Prevalence, intensity, and geographic distribution of sinus worm (*Skrjabingylus nasicola*) infection in mink (*Mustela vison*) of central Ontario

Stacey A. Santi, Glenn H. Parker, Natalie P. Schaffner, Liane Capodagli, and Michael A. Persinger

Abstract: Mink (*Mustela vison* Schreber, 1777) skulls (n = 630) from 18 geographic regions throughout central Ontario were examined for levels of sinus worm (*Skrjabingylus nasicola* (Leuckart, 1842)) infection by exposing and counting adult worms present in each sinus cavity. Site differences in both infection prevalence (range 55.6%–100%) and infection intensity (2.4 ± 0.3 to 16.1 ± 2.2 worms per infected animal; mean ± SE) were found, but neither latitudinal nor longitudinal trends were apparent. Temporal differences in infection prevalence were not observed among selected regions sampled over two and three consecutive trapping seasons; however, at two of the three sites monitored, infection intensities increased approximately twofold. Juvenile animals of either sex indicated elevated levels of infection prevalence relative to adult males, while juvenile males, but not females, indicated significantly higher infection intensities than those seen in the adult male cohort. No bias toward left or right sinus location was noted in either prevalence or intensity of infections. Comparison of age- and sex-adjusted body mass failed to provide evidence for reduced physical condition in infected animals.

Résumé : Nous avons déterminé le niveau d'infection de visons (*Mustela vison* Schreber, 1777) par le nématode parasite des sinus (*Skrjabingylus nasicola* (Leuckart, 1842)) en exposant et dénombrant les vers adultes dans chacune des cavités des sinus de crânes (n = 630) provenant de 18 régions géographiques de tout le centre de l'Ontario. Il y a des différences d'un site à l'autre dans la prévalence de l'infection (étendue 55,6 % – 100 %) et dans son intensité (2,4 ± 0,3 à 16,1 ± 2,2 vers par animal infecté; moyenne ± erreur type), mais il n'y a pas de gradient en fonction ni de la latitude ni de la longitude. Il n'y a pas de différence temporelle dans la prévalence de l'infection dans les régions choisies et échantillonnées durant deux ou trois saisons consécutives de piégeage; cependant, à deux des trois sites ayant fait l'objet de monitorage, l'intensité de l'infection a à peu près doublé. Les jeunes animaux des deux sexes possèdent des niveaux de prévalence de l'infection élevés par comparaison avec les adultes mâles; de plus, les jeunes mâles, mais non les femelles, ont des intensités d'infection significativement plus grandes que celles observées chez la cohorte des mâles adultes. Il n'y a pas de tendance préférentielle pour les sinus droits ou gauches ni dans la prévalence, ni dans l'intensité des infections. La comparaison des masses corporelles corrigées en fonction de l'âge et du sexe n'indique pas de diminution de la condition physique chez les animaux infectés.

[Traduit par la Rédaction]

Introduction

Sinus worms (genus *Skrjabingylus* Petrov, 1927) are stout crimson nematodes that inhabit the nasal sinus cavities of certain mustelids, including mink (*Mustela vison* Schreber, 1777), skunk, polecat, and weasel. The most widely distributed member of this genus, *Skrjabingylus nasicola* (Leuckart, 1842), has been the subject of considerable epidemiological study in the past.

Transmission of *S. nasicola* to its definitive host, the mink or weasel, can occur via ingestion of terrestrial gastropods harbouring the infective third-stage larvae or presumably more commonly through feeding on infected rodents, shrews, amphibians, or reptiles that serve as paratenic hosts (Hansson 1967; Gamble and Riewe 1982; Jennings et al. 1982). Following ingestion, the larvae undergo two additional molts and, by moving anteriorly through the spinal subarachnoid space to the olfactory nerves, migrate through the cribiform plate of the ethmoid bone to enter the nasal and frontal sinuses, arriving as early as 6 days post infection. Upon maturation in the sinuses, adult male worms range between 6 and 15 mm (mean of 11 mm), while females reach lengths of 10–32 mm (mean of 19 mm) (Lankester 1970; Lankester and Anderson 1971). Manifestations of infection are frequently marked by distinctive bone pathologies of the sinus region, commonly described as variants of discoloration, swelling or enlargement, and thinning or perforation of the external sinus wall (Santi 2001).

Received 18 January 2006. Accepted 24 May 2006. Published on the NRC Research Press Web site at http://cjz.nrc.ca on 19 August 2006.

S.A. Santi, G.H. Parker,[1] N.P. Schaffner, L. Capodagli, and M.A. Persinger. Department of Biology, Laurentian University, Sudbury, ON P3E 2C6, Canada.

[1]Corresponding author (e-mail: gparker@laurentian.ca).

 doi:10.1139/Z06-084 © 2006 NRC Canada

Previous studies assessing infections of *Skrjabingylus* spp. in mustelids have relied heavily upon examining museum specimens for sinus pathologies as an index of both the prevalence and the intensity of parasitism. Epidemiological studies based on observable sinus damage among weasel specimens (*Mustela erminea* L., 1758, *Mustela frenata* Lichtenstein, 1831, and *Mustela nivalis* L., 1766) indicate the widespread distribution of *S. nasicola* infection throughout North America, including regions as far north as the Northwest Territories (Dougherty and Hall 1955). Studies employing fresh specimens in which the sinuses were opened and the resident nematodes extracted confirm widespread distribution but have also provided evidence that prevalence and intensity values can vary substantially from site to site. In Ontario, the prevalence of *S. nasicola* infection among weasel and mink was found to be generally high yet variable (74%–100% at three sites examined — Chapleau, Lindsey, and Lake Huron districts; Lankester 1970). However, a survey of the prevalence and intensity of *S. nasicola* infections encompassing a broad geographical range within the Province has not been conducted to date.

Considerable variation also exists with respect to the patterns of infection occurrence and manifestation. Several studies report evidence that both prevalence and infection intensity tend to be higher in older animals (Dougherty and Hall 1955; Hansson 1969; Gamble and Riewe 1982; Fuller and Kuehn 1984), or alternatively in juveniles (Popov 1943 in Dougherty and Hall 1955; Hansson 1968), whereas other studies have reported no sex- or age-related differences (Debrot and Mermod 1980). Others have reported asymmetrical damage to the sinus region, suggesting that an infection bias to one sinus occurs (Hansson 1968; King 1977; Gamble and Riewe 1982), while other reports refute this finding (Hansson 1967; Lewis 1967). Further, reliance on museum specimens in some of these studies to determine infection prevalence and intensity values have added more confusion than clarity to these questions, since there are inherent problems in inferring levels of parasite burden without actually recovering the parasite (Dougherty and Hall 1955).

Few studies have addressed the potential impact of *S. nasicola* infection on the host animal. Popov (1943) and Lavrov (1944) both noted lower body mass among infected *M. erminea* and hypothesized that intense levels of infection could account for the subsequent decline observed in short-tailed weasel populations in the former USSR. The latter author further conjectured that such parasitic infections would have an adverse effect on the reproductive activities of afflicted animals as a result of the presumed release of helminth toxins. However, neither the release of such toxins nor their proposed chemical–physiological actions has been confirmed. Conversely, other studies have reported no evidence of reduced body mass among infected hosts (King and Moody 1982).

Based on actual worm recoveries, the present study examines the prevalence and intensity of *S. nasicola* infections in mink (*M. vison*) populations throughout central Ontario, with an aim toward assessing variations attributable to harvest year, sex, and age of the host subject, and biases in the anatomical location of infection sites. As a measure of fitness and condition, and as a means towards assessing the potential impact of the parasite upon its host subject, age- and sex-adjusted body mass of infected and noninfected animals were also compared.

Materials and methods

Frozen peltless mink carcasses (n = 630) were obtained from Ontario fur trappers between October and December of 1997, 1998, and 1999. They were derived from the following 18 geographical regions (located as shown in Fig. 1): Chapleau (CA; n = 10), Manitoulin Island (MI; n = 36), Dunchurch (DC; n = 27), Manitouwadge (MG; n = 19), Elliot Lake (EL; n = 33), Nipissing (NI; n = 75), Espanola (ES; n = 38), Perth (PE; n = 23), Fauquier (FQ; n = 22), Sault Ste. Marie (SS; n = 56), Grey Bruce (GB; n = 57), Simcoe (SC; n = 13), Hearst (HE; n = 25), Sudbury (SU; n = 91), Iron Bridge (IB; n = 13), Timmins (TI; n = 37), Kirkland Lake (KL; n = 42), and Wawa (WA; n = 13).

Specimens were weighed, sexed by genital/gonadal examination, and assigned to either a juvenile (<1 year) or adult (>1 year) age class based on the degree of temporal muscle coalescence (Poole et al. 1994). Three individuals performed the age ratings blindly and, in the uncommon event of a disagreement in classification, the skull was re-evaluated by the three raters and a (majority) concensus reached.

Using a Dremel grinding tool, the bone comprising the lateral wall of either sinus cavity was reduced to a very thin layer, which was removed manually with tweezers, and readily available worms were extracted. The sinus was then further opened with fine bone snips and all remaining worms were removed from each sinus with the aid of a stereomicroscope at low power (9.0×), immersed in a 1.0% (*m*/*v*) saline solution, and counted. The worms were then transferred to a 90% (*v*/*v*) glycerol/alcohol solution for preservation. Representative specimens of *S. nasicola* were deposited in the Canadian Museum of Nature, Ottawa, Ontario (catalogue No. CMNPA 2001-0044).

Although the worms were generally resilient to the extraction process, there were instances where removed worms were incomplete and judgments had to be made regarding count tallies. In the event that worms were broken but body portions could not be matched with confidence, only segments with a length >1/2 that of a whole worm were included in the count. In such cases, the estimate of infection intensity was considered conservative. Degenerated worms, infrequently encountered, were included in the intensity counts and their condition noted accordingly.

Statistical analyses

Hierarchical log-linear analyses followed by χ^2 post hoc analyses were used to examine infection prevalence among the geographical sites and the sex–age cohorts. Chi-square analyses were also used to examine disproportions in infection prevalence among the sex–age cohorts and in infection bias to left or right sinus cavity. Levels of infection intensity among sex–age cohorts and geographical sites were evaluated using a two-way analysis of variance (ANOVA) followed by Tukey's post hoc tests. Where violations in assumptions of homogeneity of variance or skewness of the data were noted, the data were logarithmically transformed prior to analysis, and statistics for both raw and transformed

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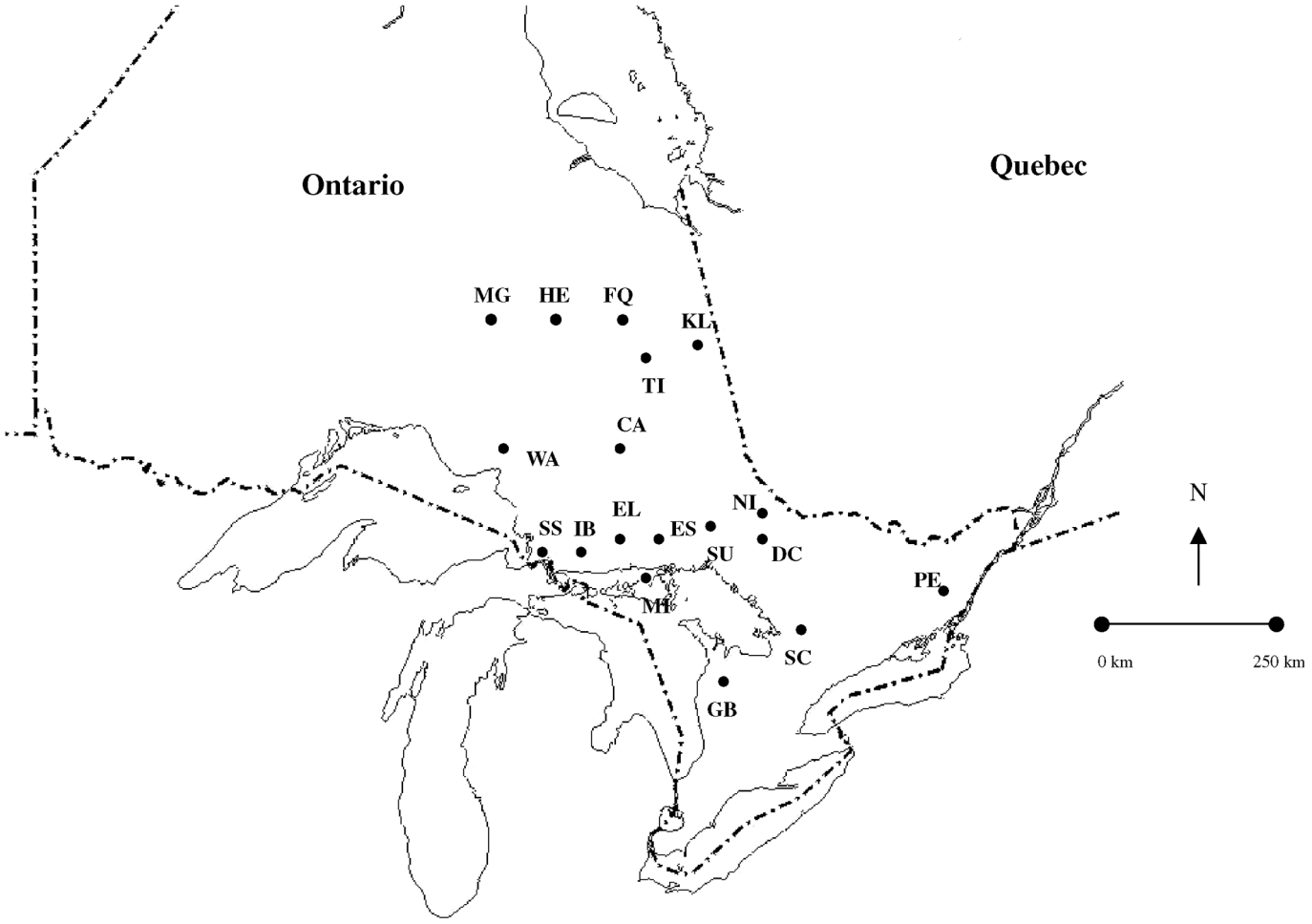
Fig. 1. Map showing locations of 18 regional sites in central Ontario from which mink (*Mustela vison*) were obtained.



data provided. Unless otherwise stated, differences have been deemed significant at $p < 0.05$. All analyses were performed on a VAX computer using SPSS software.

Results

Infection prevalence

Skrjabingylus nasicola infections were found throughout all 18 geographic regions examined. A hierarchical log-linear analysis confirmed that no significant three-way interaction existed among prevalence of infection, geographic regions, and sex–age cohorts of the host ($\chi^2_{[69]} = 77.1$, $p > 0.05$, ns). However, a significant disconcordance was attributed to differences in prevalence with respect to the geographic regions ($\chi^2_{[23]} = 90.6$, $p < 0.001$) and the sex–age cohorts ($\chi^2_{[3]} = 15.4$, $p < 0.05$). A χ^2 post hoc analysis confirmed the significant disproportion in prevalence values attributable to geographic sites ($\chi^2_{[17]} = 82.0$, $p < 0.001$). Sault Ste. Marie, Iron Bridge, and Elliot Lake showed the highest infection prevalence (100%), while Grey Bruce (59.6%) and Manitoulin Island (55.6%) were areas of lowest prevalence. Within those areas of the Province sampled, the prevalence of infection averaged 80.5%; values for individual regions are listed in Table 1.

Ordering of the geographic regions from north to south or from east to west to examine for latitudinal or longitudinal trends failed to indicate the existence of any pattern in the prevalence values obtained. A cluster analysis, performed using regional prevalence values as the classifying variable, identified three clusters but failed to indicate any geographic ordering within the cluster membership.

Differences in infection prevalence among the sex–age cohorts ($\chi^2_{[3]} = 21.4$, $p < 0.05$) were primarily attributable to an age effect. Juvenile males and juvenile females had significantly higher levels of infection prevalence (85.9% (n = 192) and 88.9% (n = 144), respectively) relative to adult males (72.5% (n = 273)). Prevalence among adult females (76.2%) was not found to differ significantly from that seen in any of the other three cohort classes — a trend possibly explained by the small number of mature females available for analysis (n = 21; 16 of which were infected). A one-way ANOVA and symmetrical χ^2 analyses, after removing adult males from the sample, further confirmed that no significant differences were present between the juvenile age classes and adult females with respect to infection prevalence.

Infection intensity

Infection intensities differed significantly among regions (raw data: $F_{[17,443]} = 13.5$, $p < 0.001$, $\eta^2 = 56\%$; log-transformed data: $F_{[17,443]} = 13.9$, $p < 0.001$, $\eta^2 = 57\%$)

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Table 1. Prevalence (n/n) and intensity of *Skrjabingylus nasicola* infection in mink (*Mustela vison*) from various regions of Ontario.

Region	Prevalence (%)	Intensity (mean ± SE)
Chapleau	9/10 (90)	6.7±1.9
Dunchurch	25/27 (92.6)	15.3±1.7
Elliot Lake	33/33 (100)	15.7±1.8
Espanola	32/38 (84.2)	6.4±0.6
Fauquier	19/22 (86.4)	5.2±0.6
Grey Bruce	34/57 (59.6)	3.9±0.7
Hearst	23/25 (92)	5.7±0.8
Iron Bridge	13/13 (100)	16.1±2.2
Kirkland Lake	26/42 (61.9)	3.3±0.5
Manitoulin Island	20/36 (55.6)	2.4±0.3
Manitouwadge	16/19 (84.2)	5.3±0.9
Nipissing	64/75 (85.3)	9.3±1.0
Perth	22/23 (95.7)	8.4±1.0
Sault Ste. Marie	56/56 (100)	13.3±1.2
Simcoe	12/13 (92.3)	8.2±1.3
Sudbury	64/91 (70.3)	4.7±0.5
Timmins	29/37 (78.4)	4.8±0.4
Wawa	10/13 (76.9)	9.4±2.7
All Regions	507/630 (80.5)	8.1±0.3

Note: Prevalence, $\chi^2 = 81.96$, $p < 0.001$, $n = 17$.

and among sex-age cohorts (raw data: $F_{[3,443]} = 4.9$, $p < 0.002$, $\eta^2 = 14\%$; log-transformed data: $F_{[3,443]} = 5.8$, $p < 0.001$, $\eta^2 = 16\%$) as indicated by a two-way ANOVA. The mean (±SE) value for all regions combined was 8.1 ± 0.3 worms per infected animal, with individual regional means ranging from a low of 2.4 ± 0.3 (Manitoulin Island) to a high of 16.1 ± 2.2 (Iron Bridge) (Table 1). Post hoc analyses (Tukey) indicated that regions with intensity values of 13.3 worms or higher per infected animal differed significantly from those with lower intensities. Ordering of the geographic regions from north to south and subsequently from east to west failed to identify any latitudinal or longitudinal epidemiological trends with respect to infection intensity.

Juvenile males showed a significantly higher mean intensity of infection (9.8 ± 0.7 worms per infected animal) than either juvenile females (6.7 ± 0.5 worms per infected animal) or adult males (7.6 ± 0.5 worms per infected animal). Intensity of infection among adult females (8.2 ± 2.0 worms per infected animal) did not differ significantly from that of any of the other three sex–age cohorts.

Relationship between infection prevalence and intensity

Visual inspection revealed that regions with the highest prevalence generally had the highest intensities of infection (Fig. 2). Correlation analyses confirmed the strong positive correlation between these two variables (raw data: Spearman's $\rho = 0.84$, $p < 0.001$; log-transformed data: Pearson's $r = 0.85$, $p < 0.001$) as shown in Fig. 3.

Temporal variations

Data from two regions (Elliot Lake and Nipissing) sampled over two consecutive trapping seasons (1997 and 1998) and from a third site (Sudbury) sampled over 3 years (1997–1999) allowed for an assessment of temporal variations in the prevalence and intensity of *S. nasicola* infections. Neither prevalence nor mean intensity of infection differed significantly among Sudbury animals over the 3 years sampled ($\chi^2_{[2]} = 0.85$, $p > 0.05$, ns; raw data: $F_{[2,61]} = 2.66$, $p > 0.05$, ns; log-transformed data: $F_{[2,61]} = 2.95$, $p > 0.05$, ns). Prevalence values at the Elliot Lake site and at Nipissing likewise remained unchanged between 1997 and 1998 ($\chi^2_{[1]} = 1.98$, $p > 0.05$, ns). Infection intensities, however, were higher in 1998 than in 1997 at both the Elliot Lake site (raw data: $F_{[1,31]} = 6.36$, $p < 0.02$, $\eta^2 = 17.0\%$; log-transformed data: $F_{[1,31]} = 7.93$, $p < 0.01$, $\eta^2 = 20.0\%$) and the Nipissing site (raw data: $F_{[1,62]} = 7.08$, $p < 0.01$, $\eta^2 = 10.3\%$; log-transformed data: $F_{[1,62]} = 8.95$, $p = 0.004$, $\eta^2 = 12.6\%$); mean intensities for the consecutive trapping years were 11.9 ± 2.0 and 20.2 ± 2.7 worms per infected animal at Elliot Lake and 8.1 ± 1.1 and 15.3 ± 2.4 worms per infection at Nipissing (Fig. 4). The annual differences in infection intensity could not be attributed to age discrepancies, as no significant interaction between harvest year and age class was observed in either the Nipissing sample (raw data: $F_{[1,60]} = 2.32$, $p > 0.05$; log-transformed data: $F_{[1,60]} = 1.10$, $p > 0.05$) or the Elliot Lake sample (raw data: $F_{[1,29]} = 0.55$, $p > 0.05$; log-transformed data: $F_{[1,29]} = 0.16$, $p > 0.05$).

Effects of infection on body mass as a condition index

A preliminary one-way ANOVA to examine the effects of *S. nasicola* infection on the body mass of the host suggested that infected animals had lower body mass (583.9 ± 7.5 g) than uninfected mink (652.8 ± 14.3 g). However, when variance attributable to disproportions in different sex–age cohorts within the sample was accounted for in the analysis, this effect disappeared ($F_{[1,622]} = 2.16$, $p > 0.05$, ns). No significant correlation ($r = -0.042$, $p > 0.05$) was found between body mass and the total number of *S. nasicola* present in examined animals.

Bias for left vs. right sinus infection

A χ^2 analysis investigating bias in infection site determined that left and right sinuses were infected at approximately equal frequencies ($\chi^2_{[1]} = 0.30$, $p > 0.05$, ns). Single (one sinus only) infections to the left and right sinuses occurred in 102 (20.1%) and 110 (21.7%) cases, respectively. A higher proportion of animals (292; 58.2%) sustained infection in both sinus cavities concurrently (double sinus infection) compared with single sinus infections ($\chi^2_{[1]} = 13.59$, $p < 0.001$]. Infection intensity did not differ significantly between left and right sinus cavities ($t = 1.21$, $n = 507$, $p > 0.05$, ns), which harboured 4.1 ± 0.2 worms per cavity.

Discussion

Prevalence

Despite indication that prevalence values among regions vary substantially, the results of the present study demonstrate the ubiquitous distribution of *S. nasicola* in mink populations throughout central Ontario. Trends toward widespread yet varying prevalences of infection have likewise been reported by others examining the epidemiology of *S. nasicola* among wild mustelids. King (1977) examined *M. nivalis* skulls

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Fig. 2. Prevalence (solid bars) and intensity (mean ± SE; open bars) of *Skrjabingylus nasicola* in Ontario mink (arranged from high to low prevalence).

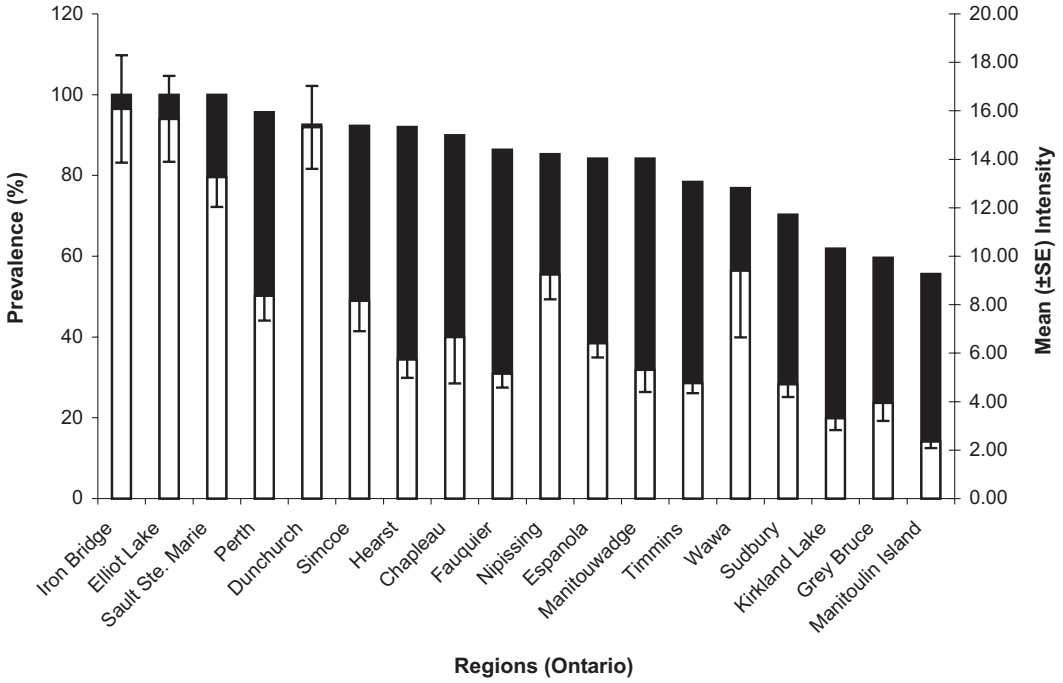
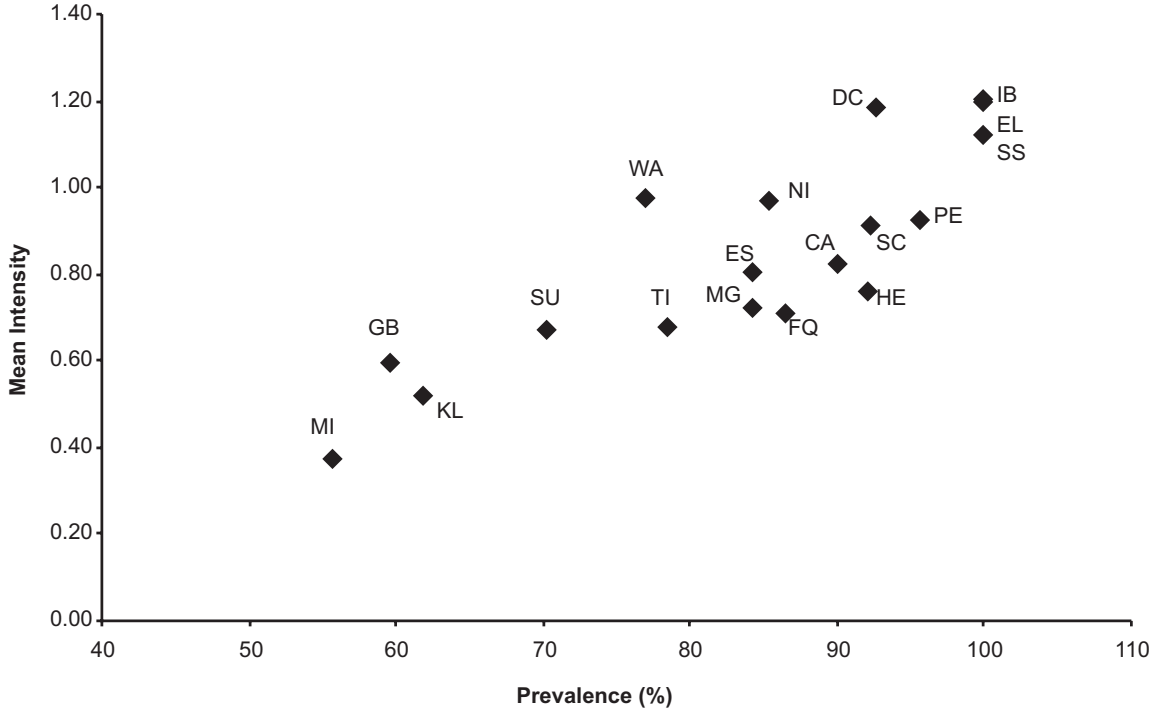


Fig. 3. Pearson correlation between mean intensity (log-transformed) and prevalence of *S. nasicola* infection in Ontario mink ($r = 0.85$, $r^2 = 0.72$, $p < 0.001$).



from Britain and found large regional differences with respect to infection prevalence (0%–69%), but failed to report whether geographic patterns (i.e., north–south or east–west) existed. van Soest et al. (1972) likewise found substantial geographic differences among various regions examined in the Netherlands, with prevalence values varying from 17% to 100% of examined *M. erminea*. King and Moody (1982) found significant regional differences in prevalence values among *M. erminea* in New Zealand, even for some areas located as close as 5 km apart, but remained uncertain of the epidemiological significance, if any, of this observation.

Despite regional variability, prevalence values reported in the present study indicate that parasitism of Ontario mink by *S. nasicola* is generally high. The only other published data for *S. nasicola* infection in Ontario mink are those of Lankester (1970) who reported prevalence values of 74% in

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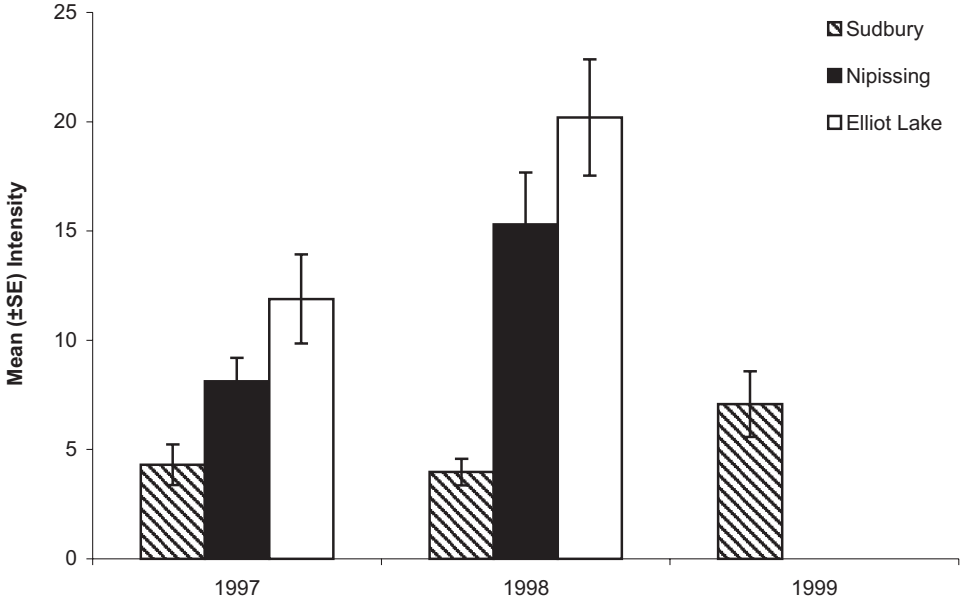
Fig. 4. Bar graph showing temporal differences in the intensity (mean ± SE) of *S. nasicola* infection at three sampling sites.



Chapleau, 79% in the Lake Huron District, and 100% in the Lindsay District. Both the provincial average (80.5%) and the range of prevalence values (56%–100%) obtained in our study seem aligned with those of Lankester (1970), which were determined almost 3 decades ago. This general concordance, coupled with the apparent lack of change in prevalence values over the 2–3 year trapping period examined in the present study, suggest that ecophysiological conditions contributing to infection prevalence in Ontario mink are relatively stable. This conjecture is in keeping with Duncan's (1976) contention that *Skrjabingylus* is a successful genus based on the widespread distribution of the parasite and the apparent high intensity of infection that can be tolerated by the host.

Hansson (1969) hypothesized that regional differences in prevalence could be due to the absence or varying abundance of suitable environmental vectors for transmission. If the intermediate host vector of *S. nasicola* were more definitive (i.e., confined to a single species), a more restricted and delineated geographic distribution of the parasitic nematode should result. Such a scenario would allow parasitologists to accurately predict regions where *S. nasicola* infections might be found based on areas in which the intermediate host is known to occur, or alternatively, to identify which geographic regions support the full complement of biotic factors (e.g., availability of both the intermediate and paratenic host species) promoting *S. nasicola* infection. The high prevalence and ubiquitous distribution of infections seen in the present study, however, are in keeping with the current view that several species of intermediate and paratenic hosts likely serve as the required vectors in transmission, thus extending an otherwise more-tightly circumscribed distribution of *S. nasicola*.

In examining skulls of *M. erminea* and *M. frenata* collected throughout North America, Dougherty and Hall (1955) reported a correlation between climate and the occurrence of *S. nasicola* infections, noting colder more northern climates to be associated with fewer cases of infection than warmer forested areas marked by milder temperature and more abundant rainfall, where higher incidences were observed. Studies conducted by Hansson (1969), King (1977), and Kirkland and Kirkland (1983) tended to corroborate this finding, although in some cases infection was only inferred from an index of skull damage rather than verified through actual recovery of the parasite. Past research conducted on larval survival (Hansson 1974) has shown *S. nasicola* to be highly sensitive to freezing and desiccation, and hence, a warmer, more humid climate would appear to be ideal for promoting parasitic transmission. Furthermore, the distribution of terrestrial gastropods essential as intermediate hosts in the life cycle of *Skrjabingylus* spp., has been shown to vary directly with environmental moisture levels (Fuller and Kuehn 1984). In contrast to the above observations and the inference that latitudinal differences in infection parameters might be expected, no such trends were noted for either the prevalence or the intensities of *S. nasicola* infection in Ontario mink of the present study. It may be that the absence of geographical patterns is attributable to the small spatial scale involved (central Ontario) compared with the continent-wide study area examined by Dougherty and Hall (1955). Although latitudinal trends were not found, it is interesting to note that regions with 100% prevalence of infection (Elliot Lake, Iron Bridge, Sault Ste. Marie) were all located in western central Ontario along an area bounded by the North Channel of Lake Huron. The ecological significance of this observation is not currently known, but further investigations to confirm this localized pattern and to explore the potential causative factors may be warranted.

Intensity

Variation in the literature also exists with respect to infection intensity. Kinsey and Longley (1963) reported as many as 63 worms present in one mink, a value slightly higher than the maximum value obtained in this study (55 worms in one Sault Ste. Marie animal). Lankester (1970) reported a maximum of 44 worms from an infected mink in the Lindsay District. The mean intensity of infections in the present study (~8 worms per infected animal) is higher than that reported by Lankester (1970) for his Ontario sample (5 worms per in-

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fected animal), and likewise higher than the value noted by Hansson (1968) in her study of mink in Sweden (2 worms per animal). Whether the difference in infection intensity between Lankester's (1970) study and results obtained in the present study is attributable to geographic differences in sampling or can be interpreted as evidence that infection intensity is increasing requires further sampling over consecutive trapping seasons at all designated sites.

Temporal data obtained in this study showed that intensity values for Nipissing and Elliot Lake, although not for Sudbury, almost doubled in the 2nd year of sampling. The source of the substantial increase in infection intensity between consecutive years is unclear. Citing evidence of increased bone damage in the skulls of adult compared with juvenile specimens as support, several authors have postulated that adult specimens, having tolerated initial infection, may become re-infected during the 2nd and (or) subsequent years, thus resulting in progressively higher worm counts with age (Gamble and Riewe 1982; King 1989). Our data do not support this conjecture, however, as infection intensities at both the Nipissing site and the Elliot Lake site were not found to differ between juvenile and adult animals; assessments of infection intensity were also not confounded with age-class × harvest-year interactions. We propose that an alternative and more plausible explanation for the higher levels of infection intensity during 1998 might be a greater abundance of paratenic hosts harboring equal or greater numbers of infective third-stage larvae, or possibly a higher density of intermediate hosts housing first-stage larvae.

It is noteworthy that mean infection intensities were positively correlated with prevalence values across the 18 geographic regions examined; in fact, all areas that reached 100% prevalence also had the highest levels of infection intensity recorded (Pearson's $r = 0.85$). Similarly, King and Moody (1982) found a positive relationship between infection prevalence and the number of *S. nasicola* worms present in short-tailed weasel ($r = 0.79$), although the relationship obtained in their study was largely driven by values from one geographical region. We contend that if more *S. nasicola* larvae are shed into the environment owing to a larger number of infected animals, then there should be a greater probability of direct and (or) indirect encounter by paratenic and definitive hosts, respectively, thus sustaining both higher frequencies and higher intensities of infection.

Sex–age cohorts

Much variation exists in the literature with respect to sex–age differences in the prevalence and intensity of *S. nasicola* infection among mustelids. Debrot and Mermod (1980) found no difference in prevalence values between juvenile and adult weasels (*M. erminea*). Similar results were reported by King and Moody (1982) for subadult and adult *M. erminea* in New Zealand. The results obtained in the present study are in disagreement with the above cited findings in that juvenile mink had a significantly higher prevalence of infection relative to adult males in the sample. Popov (1943; in Anderson 1971) reported that *M. erminea* and *M. nivalis* skulls in older age groups showed a decrease in the prevalence of bone lesions, and conjectured that heavily-infected younger animals possibly died from *S. nasicola* infection before reaching adulthood. Lavrov (1956) suggested that infection by *S. nasicola* could potentially cause a decline in the population of *M. erminea*, thereby diminishing the fur harvest; it was not conjectured whether the implied mortality might affect juvenile and adult animals uniformly or differentially. However, given the failure of this parasite to affect body condition in animals of the present study and the lack of evidence within the literature to substantiate the view that *S. nasicola* infection constitutes a significant mortality factor among mustelids, it would appear unlikely that the reduced prevalence of infection in adult relative to juvenile mink reported here is attributable to parasite-related mortality.

Infection intensity patterns were generally similar to those seen for prevalence in that juvenile males (although not females) harboured elevated numbers of the parasite. Hansson (1969) also found a tendency for infection intensity to be higher in younger *M. vison* than in older animals. Hansson (1968) did not find any sex or age differences with respect to infection intensity in *M. vison*, *Mustela putorius* L., 1758, *M. nivalis*, and *M. erminea*, although admittedly sample sizes were perhaps too limited to allow for rigorous comparisons. In the absence of evidence for age-selective parasite-induced mortality, we propose that the lower intensity, as well as prevalence, of *S. nasicola* infection shown by adult mink may reflect an acquired immunity in the mature animal (Maruyama and Nawa 2002).

Although juvenile animals of either gender might thus be expected to exhibit elevated intensities of infection, in actuality only male subjects indicated intensities above the adult level. The lower intensity seen in juvenile females may be reflective of the less extensive hunting patterns of females compared with their male counterparts (Linscombe et al. 1982), thus presenting lesser opportunity for encountering infected paratenic hosts.

Effects of infection on body mass as a condition index

Infection had no significant effect on the body mass of mink, a finding contrary to that of Lavrov (1944) who reported lower mass in ermine that were infected with *Skrjabingylus*. The view that smaller mustelids, such as ermine, are more likely to be adversely affected by *Skrjabingylus* infection compared with larger mustelids, such as mink, seems unlikely, as King (1977) found that infected least weasels (*M. nivalis*), among the smallest of mustelid species, were not significantly smaller or lighter than those uninfected. Other than observed damage to the sinus bones and the tissue pathology associated with larval migration, it is unknown to what extent other pathophysiological changes are induced in subjects harboring *Skrjabingylus* infection. Future studies investigating other measures of conditional status, including differential blood cell counts and splenic–lymphatic node changes, in mink infected with *Skrjabingylus* may shed further light on the dynamics of this parasite–host relationship.

Bias in infection sites

Asymmetry in infection was not found in this study. Likewise, Hansson (1968) found no difference in infection prevalence between the sinus cavities in *M. nivalis*, *M. erminea*, *M. putorius*, *M. vison*, or *Martes martes* (L., 1758). However, King (1977) found that a greater proportion of sinus damage (indicative of prevalence) was sustained on the

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left side in *M. nivalis*, whereas Gamble and Riewe (1982) found an infection bias towards the right sinus cavity in their sample of long-tailed weasels (*M. frenata)*. The biological significance of these observations in relation to the findings reported in the present study are not currently understood, and the factors that control *S. nasicola* migration (e.g., chemical or hormonal) to assist in directing and establishing a more pre-determined migratory pattern for the larval parasite, have yet to be elucidated.

Acknowledgements

Special thanks and appreciation are extended to M.W. Lankester for providing definitive identification of the nematodes, to E. Addison for suggestions on ageing techniques, and to all Ontario trappers who graciously provided carcasses for the study. Financial assistance was provided through the Laurentian University Research Program (G.H.P.) and an Ontario Graduate Scholarship in Science and Technology (OGSST) – Tembec Award (S.A.S.).

References

Anderson, R.C. 1971. Metastrongyloid lungworms. *In* Parasitic diseases of wild mammals. *Edited by* J.W. Davis and R.C. Anderson. Iowa State University Press, Ames. pp. 81–126.

Debrot, S., and Mermod, C. 1980. Cranial helminth parasites of the stoat and other mustelids in Switzerland. *In* Proceedings of the Worldwide Furbearer Conference, Frostburg, Maryland, 3–11 August 1980. Vol. 2. *Edited by* J.A. Chapman and D. Pursley. University of Maryland Press, College Park. pp. 690–705.

Dougherty, E.C., and Hall, E.R. 1955. The biological relationships between American weasels (genus *Mustela*) and nematodes of the genus *Skrjabingylus* Petrov, 1927 (Nematoda: Metastrongylidae), the causative organisms of certain lesions in weasel skulls. Rev. Iber. Parasitol. Tomo Extraordinario. pp. 531–576.

Duncan, N. 1976. Theoretical aspects concerning transmission of the parasite *Skrjabingylus nasicola* (Leukart 1842) to stoats and weasels, with a review of the literature. Mammal Rev. **6**: 63–74.

Fuller, T.K., and Kuehn, D.W. 1984. *Skrjabingylus chitwoodorum* (Hill, 1939) (Nematoda: Metastrongyloidea) in striped skunks from Northcentral Minnesota. J. Wildl. Dis. **20**: 348–350. PMID:6530727.

Gamble, R.L., and Riewe, R.R. 1982. Infestations of the nematode *Skrjabingylus nasicola* (Leukart 1842) in *Mustela frenata* (Lichenstein) and *M. erminea* (L.) and some evidence of a paratenic host in the life cycle of this nematode. Can. J. Zool. **60**: 45–52.

Hansson, I. 1967. Transmission of the parasitic nematode *Skrjabingylus nasicola* (Leuckart 1842) to species of Mustela (Mammalia). Oikos, **18**: 247–252.

Hansson, I. 1968. Cranial helminth parasites in species of Mustelidae. I. Frequency and damage in fresh mustelids from Sweden. Oikos, **19**: 217–233.

Hansson, I. 1969. Cranial helminth parasites in species of Mustelidae. II. Regional frequencies of damage in preserved crania from Denmark, Finland, Sweden, Greenland, and the northeast of Canada compared with the helminth invasion in fresh mustelid skulls from Sweden. Ark. Zool. **22**: 571–594.

Hansson, I. 1974. Seasonal and environmental conditions affecting the invasion of mustelids by larvae of the nematode *Skrjabingylus nasicola*. Oikos, **25**: 61–70.

Jennings, D.H., Threlfall, W., and Dodds, D.G. 1982. Metazoan parasites and food of short-tailed weasels and mink in Newfoundland, Canada. Can. J. Zool. **60**: 180–183.

King, C.M. 1977. The effects of the nematode parasite *Skrjabingylus nasicola* on British weasels (*Mustela nivalis*). J. Zool. (1965–1984), **182**: 225–249.

King, C.M. 1989. The natural history of weasels and stoats. Comstock Publishing Associates (Cornell University Press), Ithaca, N.Y.

King, C.M., and Moody, J.E. 1982. The biology of the stoat (*Mustela erminea*) in the national parks of New Zealand. VI. Infestation with *Skrjabingylus naiscola*. N.Z. J. Zool. **9**: 131–140.

Kinsey, C., and Longley, Wm.H. 1963. Incidence of *Skrjabingylus* in Minnesota mink. J. Mammal. **44**: 261.

Kirkland, G.L., and Kirkland, C.J. 1983. Patterns of variation in cranial damage in skunks (Mustelidae: Mephitinae) presumably caused by nematodes of the genus *Skrjabingylus* Petrov, 1927 (Metastrongyloidea). Can. J. Zool. **61**: 2913–2920.

Lankester, M.W. 1970. The biology of *Skrjabingylus* spp. (Metastrongyloidea: Pseudaliidae) in mustelids (Mustelidae). Ph.D. thesis, University of Guelph, Guelph, Ont.

Lankester, M.W., and Anderson, R.C. 1971. The route of migration and pathogenesis of *Skrjabingylus* spp. (Nematoda: Metastrongyloidea) in Mustelids. Can. J. Zool. **49**: 1283–1293. PMID:5106429.

Lavrov, N.P. 1944. Effect of helminth invasions and infectious diseases on variations in numbers of the ermine. *In* Biology of Mustelids, Some Soviet Research. Vol. 1. *Translated by* C.M. King. 1975. British Library Lending Division, Boston Spa, Yorkshire, UK.

Lavrov, N.P. 1956. Characteristics and causes of the prolonged depression in numbers of the ermine in forest-steppe and steppe zones of USSR. *In* Biology of Mustelids, Some Soviet Research. Vol. 1. *Translated by* C.M. King. 1975. British Library Lending Division, Boston Spa, Yorkshire, UK.

Lewis, J.W. 1967. Observations on the skull of Mustelidae infected with the nematode, *Skrjabingylus nasicola*. J. Zool. (1965–1984), **153**: 561–564.

Linscombe, G., Kinler, N., and Aulerich, R.J. 1982. Mink (*Mustela vison*). *In* Wild mammals of North America. *Edited by* J.A. Chapman and G.A. Feldhamer. Hopkins University Press, Baltimore, Md.

Maruyama, H., and Nawa, Y. 2002. Immunology of nematode infection. *In* The biology of nematodes. *Edited by* D.L. Lee. Taylor and Francis, New York. pp. 457–481.

Poole, K.G., Matson, G.M., Strickland, M.A., Magoun, A.J., Graf, R.P., and Dix, L.M. 1994. Age and sex determination for American martens and fishers. *In* Martens, sables and fishers: biology and conservation. *Edited by* S.W. Buskirk, S. Harestad, M.G. Raphael, and R.A. Powell. Comstock Publishing Associates (Cornell University Press), Ithaca, N.Y.

Popov, V.A. 1943. Numerosity of *Mustela erminea* Pall. as affected by *Skrjabingylus* invasion. Comp. R. Acad. Sci. URSS, **39**(4): 160–162. *Cited in* E.C. Dougherty and E.R. Hall. 1955. The biological relationships between American weasels (genus *Mustela*) and nematodes of the genus *Skrjabingylus* Petrov, 1927 (Nematoda: Metastrongylidae), the causative organisms of certain lesions in weasel skulls. Rev. Iber. Paraitol. Tomo Extraordinario. pp. 531–576.

Santi, S.A. 2001. Studies on the geographic distribution, prevalence, intensity and bone pathology of sinus worm (*Skrjabingylus* spp.) infection in mustelid species. M.Sc. thesis, Department of Biology, Laurentian University, Sudbury, Ont.

van Soest, R.W., van der Land, J., and van Bree, P.J.H. 1972. *Skrjabingylus nasicola* (Nematoda) in skulls of *Mustela erminea* and *Mustela nivalis* (Mammalia) from the Netherlands. Beaufortia, **265**: 85–97.

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